

CO₂alescence

Exploring the Material Applications of Atmospheric CO₂

SuperGreen : Regenerative Materials, Structures & Aesthetics

IDE
INNOVATION
DESIGN
ENGINEERING



Imperial College
London



CONCEPT

CO₂alescence

In the face of an escalating climate crisis, CO₂ is primarily recognized as a greenhouse gas driving global warming. Despite extensive efforts to capture and reduce atmospheric CO₂, its potential as a transformative design material remains largely untapped.

This project explores how CO₂ can be harnessed as a material in design processes, inviting us to reimagine its use in crafting everyday objects.

Ultimately, this work aims to encourage a shift toward responsible material usage, fostering a healthier, more resilient planet while subtly enhancing our daily lives through homewear design.

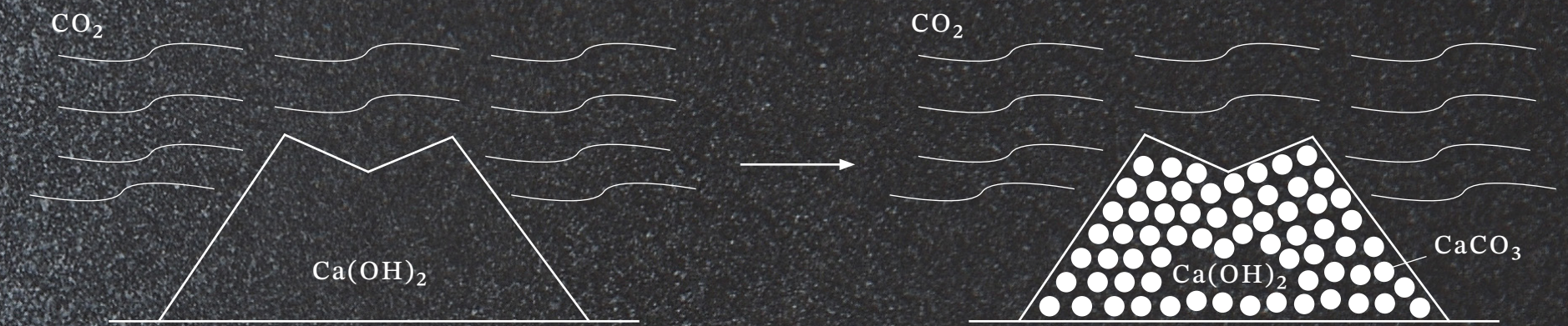
Methods

To capture ambient CO₂ as a usable design material, I investigated various methods including carbonation, carbon mineralization, electrolysis, and microalgae-based carbon capture. Considering facility limitations and overall feasibility, I chose to focus on carbonation and Photosynthesis (microalgae-based carbon capture) for my experiments.

Method 1

Carbonation

By using Ca(OH)₂, CO₂ reacts to form CaCO₃, effectively sequestering carbon in a stable, solid form.



Carbonation is a chemical reaction in which calcium hydroxide Ca(OH)₂ reacts with carbon dioxide CO₂ to form calcium carbonate CaCO₃ and water.

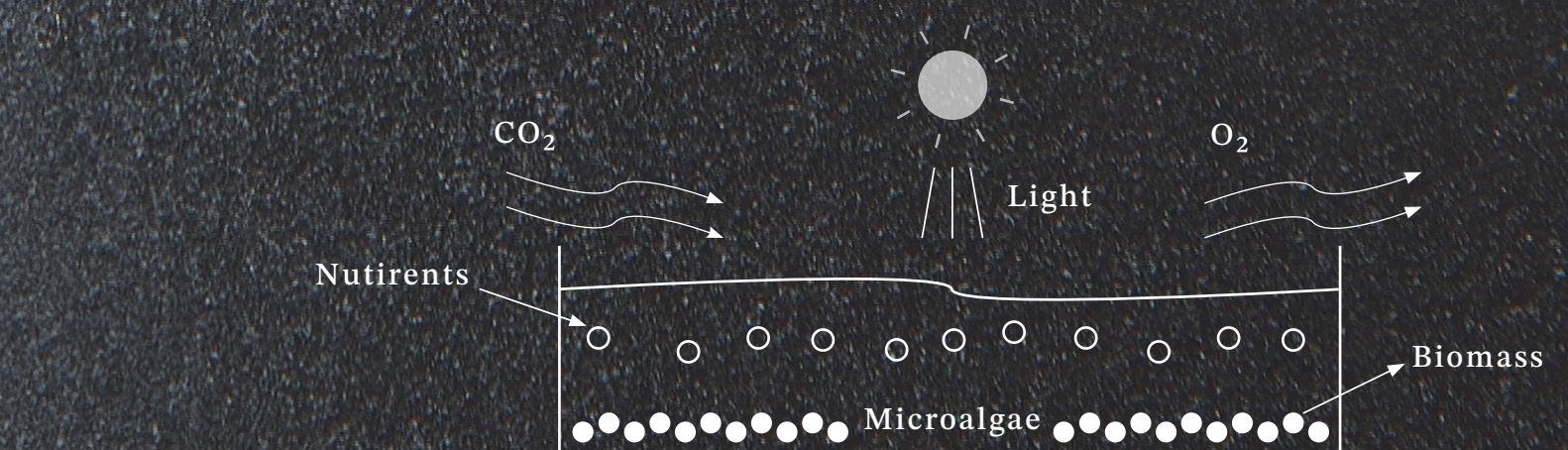
Calcium hydroxide is widely available due to its high

production and can be sourced from industrial waste streams, such as wasted cement and byproducts like steel slag. This project explores the potential of using Ca(OH)₂ to sequester ambient CO₂.

Method 2

Photosynthesis

Microalgae perform photosynthesis and capture CO₂ from the air, converting it into organic biomass.



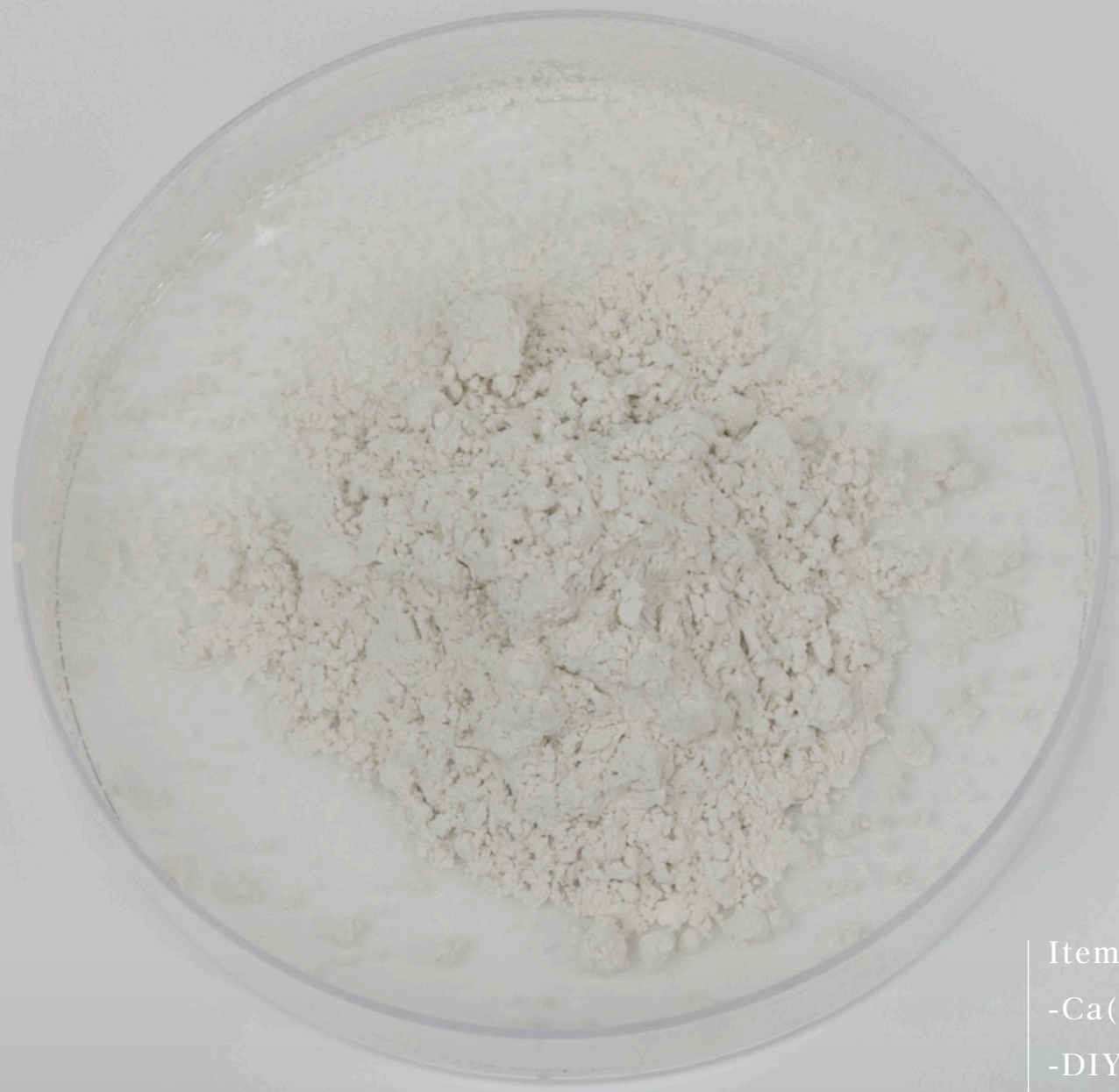
Microalgae use light to create energy through photosynthesis. They absorb light using pigments and take in CO₂ and water to produce glucose, a simple sugar that serves as a building block for the cell. This glucose is then used to build the

overall biomass of the microalgae. Nutrients help support their growth, while oxygen is released as a byproduct. Overall efficiency depends on light intensity and CO₂ levels.

Carbonation

26.4g of CO₂

captured in Riverside, 1 Hester Rd, London

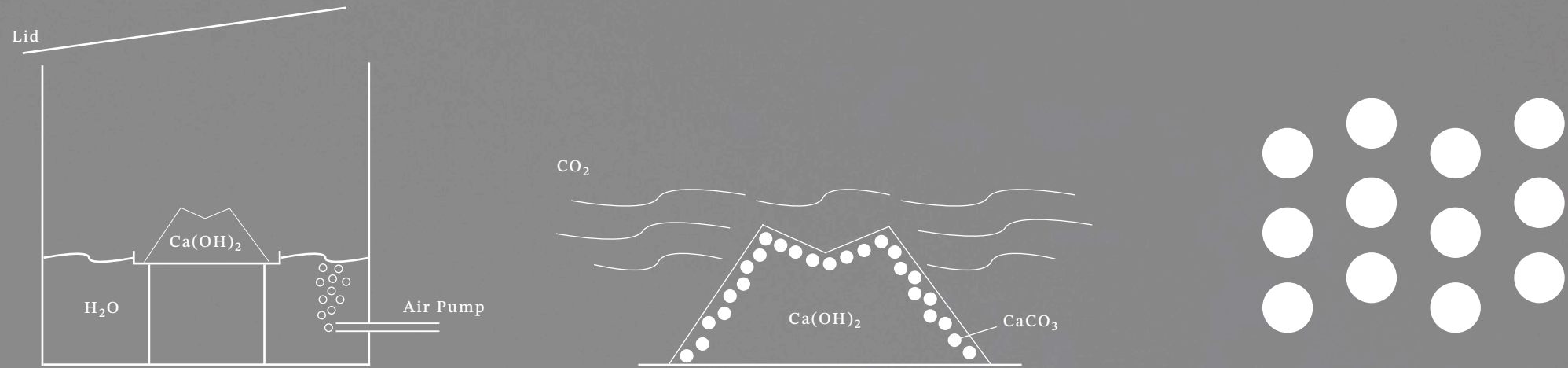


- Items
- Ca(OH)₂ powder
 - DIY Humidifier
 - Air Pump

I referenced an open-source DIY Direct Air Capture system called Cyan (CC-BY-SA-4.0) to develop a custom humidifier that moistens Ca(OH)₂ for efficient CO₂ capture. The device forms a thin water film on Ca(OH)₂, allowing CO₂ to dissolve as carbonic acid (H₂CO₃) and react with Ca(OH)₂ to form calcium carbonate

(CaCO₃). Without enough moisture, CO₂ remains less soluble, slowing the reaction. The resulting Ca(OH)₂ and CaCO₃ mixture is used as a filler to reinforce material composition. Additionally, Ca(OH)₂ can be sourced from the lime cycle in paper and pulp mills.

Process Overview



Humidifying

The original device humidifies Ca(OH)₂ to enhance its ability to capture CO₂ efficiently. The process works by forming a thin water film on the Ca(OH)₂, which facilitates the dissolution of CO₂ into carbonic acid (H₂CO₃). Without sufficient moisture, CO₂ remains less soluble, which slows the reaction.

* I referenced an open-source DIY Direct Air Capture (DAC) system called Cyan (License Code: CC-BY-SA-4.0) and developed an original humidifier inspired by its methodology.

Dehydrating

After humidifying for a few hours, this acid reacts with Ca(OH)₂ to form calcium carbonate (CaCO₃) during the process of dehydrating. It continues capturing CO₂, and its weight increases until it reaches its capacity limit.

Harvesting

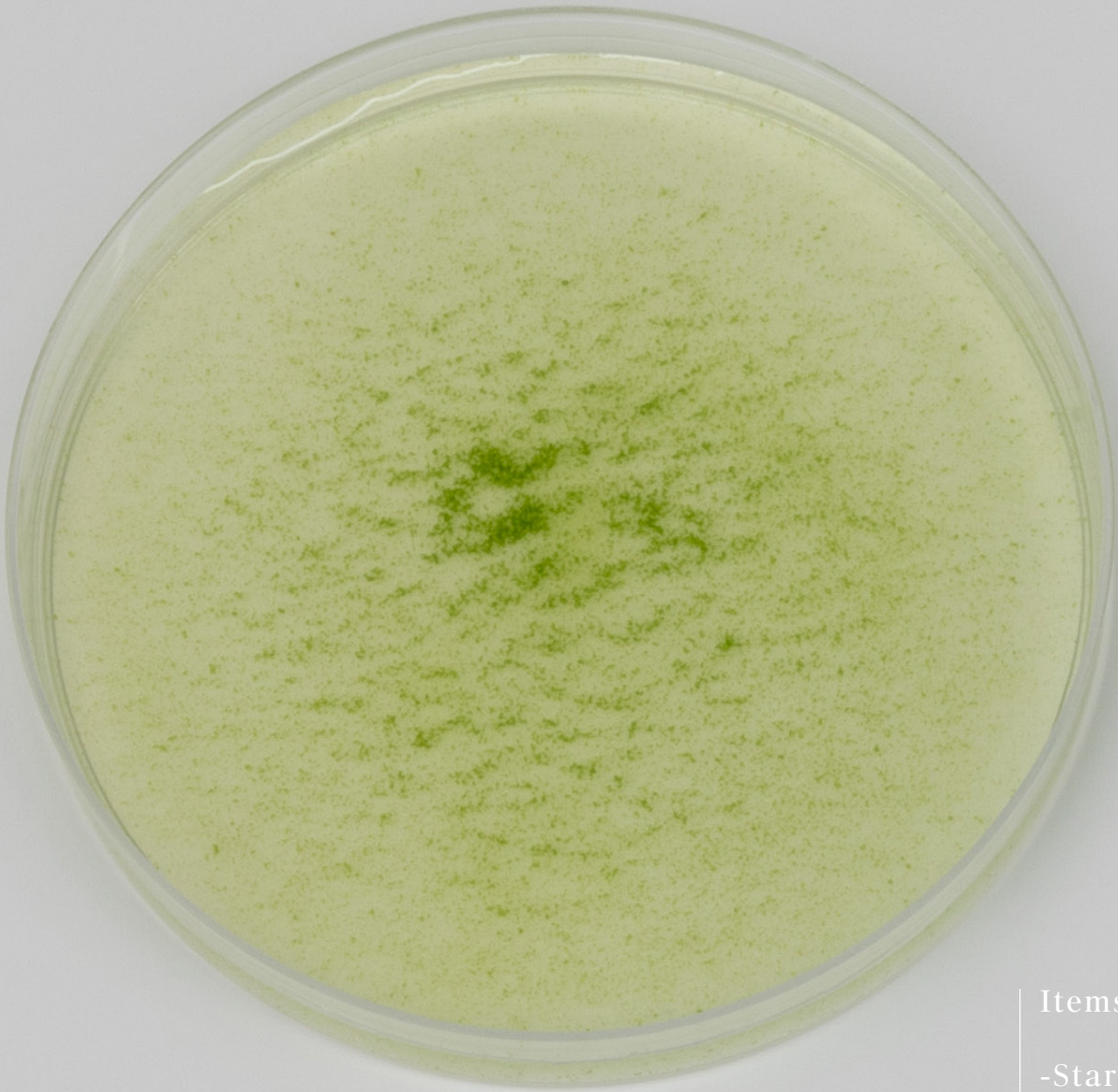
The process works by forming a thin water film on the Ca(OH)₂, which facilitates the dissolution of CO₂ into carbonic acid (H₂CO₃). This acid then reacts with Ca(OH)₂ to form calcium carbonate (CaCO₃). Without sufficient moisture, CO₂ remains less soluble, which slows the reaction.



Photosynthesis

31.2g of CO₂

captured in 26 Woodfall Street, London

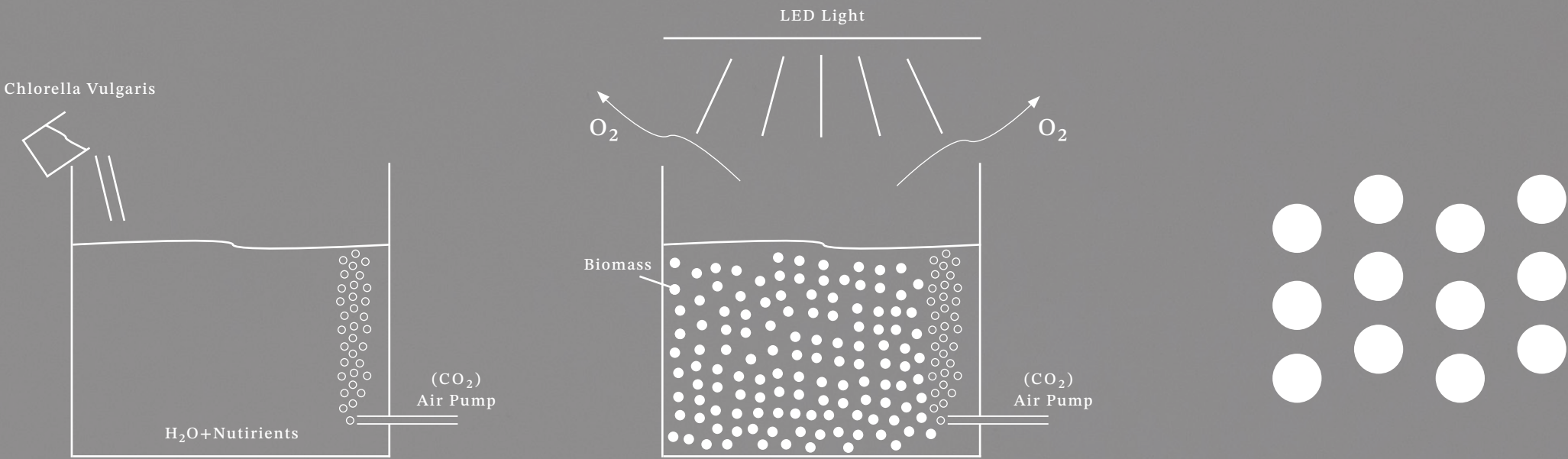


- Items
- Starter Culture
 - Medium(Nutrition Mix)
 - Air pump
 - LED Light

In addition to this approach, I chose to incorporate microalgae-based carbon capture using Chlorella vulgaris. As an efficient photosynthetic organism, Chlorella vulgaris absorbs ambient CO₂ under sufficient light conditions and

continuously converts it into renewable biomass. This process not only contributes to carbon capture but also provides a sustainable source of organic material, further supporting the principles of regenerative design.

Process Overview



Culturing

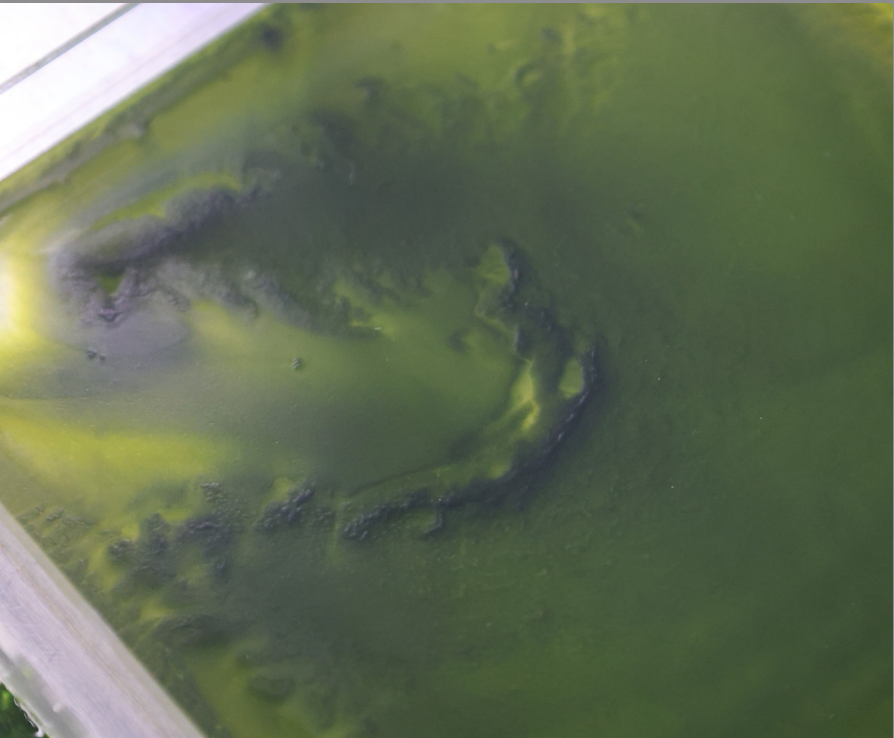
For this project, I chose Chlorella vulgaris because it is easy to cultivate. I poured the starter culture into water mixed with nutrients and set up LED lights and an air pump to support its photosynthesis.

Photosynthesis

While maintaining a water temperature of 25-30°C and a LED light cycle of 16 hours on and 8 hours off, Chlorella vulgaris photosynthesizes to produce biomass. During this process, it absorbs CO₂ and generates both biomass and O₂.

Harvesting

After it has grown sufficiently, remove the biomass that has settled at the bottom and let it dry. For this project, the harvested biomass is used as a filler to strengthen the material.



Binding Material



In pursuit of a suitable binding material, I experimented with starch, gelatin, agar, and pine resin. I found that all except pine resin were unstable. They tended to shrink and required a long time to set. Consequently, I selected pine resin as the optimal binder.

Moreover, pine resin offers significant advantages in enhancing product longevity. If a product is damaged, it can be repaired by remelting the resin to fuse the parts without the need for additional materials, effectively extending its lifecycle almost indefinitely.

Design

Design for “CO₂alescence”.

In quiet union, elements drift and merge,
not like rigid pieces of a puzzle,
but as fluid shapes that soften and intertwine.

They fuse into a single, living tapestry,
vague, organic, and ever-evolving,
each line a subtle echo of the other,
harmonizing into a resilient whole.



Reference

Binding Material Exploration

■ Material Recipe

A1: Water 60g / Starch 12g / Glycerin 6g

A2: Water 60g / Starch 12g / Glycerin 18g

B: Water 60g / Starch 6g / Agar 6g / Glycerin 6g

C1: Water 60g / Starch 6g / Gelatin 6g / Glycerin 6g / Vinegar 6g

C2: Water 60g / Starch 6g / Gelatin 6g / Glycerin 12g / Vinegar 6g

C3: Water 60g / Starch 6g / Gelatin 6g / Glycerin 18g / Vinegar 6g

D: Water 60g / Starch 6g / Gelatin 6g / Glycerin 18g / Vinegar 6g / Chlorella Powder 6g

E: Water 60g / Agar 12g/ Glycerin 12g

F: Pine Rosin 50g / Linseed Oil 15g

G: Pine Rosin 50g / Rapseed Oil 15g

H1: Pine Rosin 50g / Chrollela Powder 15g

H2: Pine Rosin 50g / Chrollela Powder 30g

H3: Pine Rosin 50g / Chrollela Powder 30g / Beeswax 10g

I: Water 130g / Sodium Alginate 3.25g / CaCO3 130g



Reference

Carbon Footprint Assessment (Brief Overview)

To explore the use of CO₂ as a material in design, a brief carbon footprint calculation for this project has been conducted (excluding material sourcing due to limited data).

1. Carbonation via Ca(OH)₂ Method

•Energy Use: Air pump (2 W continuous) ≈ 2.5 kWh; LED lighting (135 W for 16 h/day) ≈ 112.3 kWh; Hotplate (1000 W for 10 min) ≈ 0.167 kWh. Total electricity consumed is about 115 kWh over the project.

•Electricity Emissions: Because the primary energy source was Octopus Energy (a 100% renewable electricity provider), the operational carbon emissions are effectively near-zero. Octopus’s supply is from zero-carbon sources, yielding ~0 g of CO₂ per kWh.

※Octopus Energy, ‘Green’, n.d. <https://octopus.energy/green/> [accessed 15 February 2025].

•CO₂ Captured: The process produced 45 g of CaCO₃ solid. Given calcium carbonate’s composition (CaCO₃ has a molar mass ~100 g/mol and contains one CO₂ (44 g/mol) per molecule.), 60.14 g CaCO₃ corresponds to roughly 26.44 g of CO₂ sequestered (≈0.026 kg of CO₂).

※MyTutor, ‘What Mass of CO₂ Will Be Produced When 50 g of CaCO₃ Decomposes?’, n.d. <https://www.mytutor.co.uk/answers/4128/GCSE/Chemistry/What-mass-of-C-O2-will-be-produced-when-50-g-of-Ca-C-O3-decomposes/> [accessed 15 February 2025].

Net Result

-26.4 g of CO₂
(≈0.026 kg of CO₂ / Approximately)

Microalgae-Based Carbon Capture (*Chlorella vulgaris*)

•Energy Use: This setup uses the same equipment and schedule as Method 1 (air pump, LED lights, hotplate), totaling roughly 115 kWh of electricity usage.

•Electricity Emissions: (Identical to the previous calculation.)

Because the primary energy source was Octopus Energy (a 100% renewable electricity provider), the operational carbon emissions are effectively near-zero. Octopus’s supply is from zero-carbon sources, yielding ~0 g of CO₂ per kWh.

※Octopus Energy, ‘Green’, n.d. <https://octopus.energy/green/> [accessed 15 February 2025].

•CO₂ Captured: Yielded 17.01 g of dry microalgal biomass. Microalgae biomass is about 50% carbon by weight; in fact, 1 g of algal dry mass fixes ~1.88 g of CO₂ from the atmosphere. Therefore, 17.01 g of *Chlorella vulgaris* would contain carbon from roughly 31.2 g of CO₂ (≈0.031 kg CO₂).

※NCBI, ‘The CFR value is not air mixture’, n.d. <https://pmc.ncbi.nlm.nih.gov/articles/PMC9605657/#:~:text=The%20CFR%20value%20is%20not,air%20mixture> [accessed 15 February 2025].

Net Result

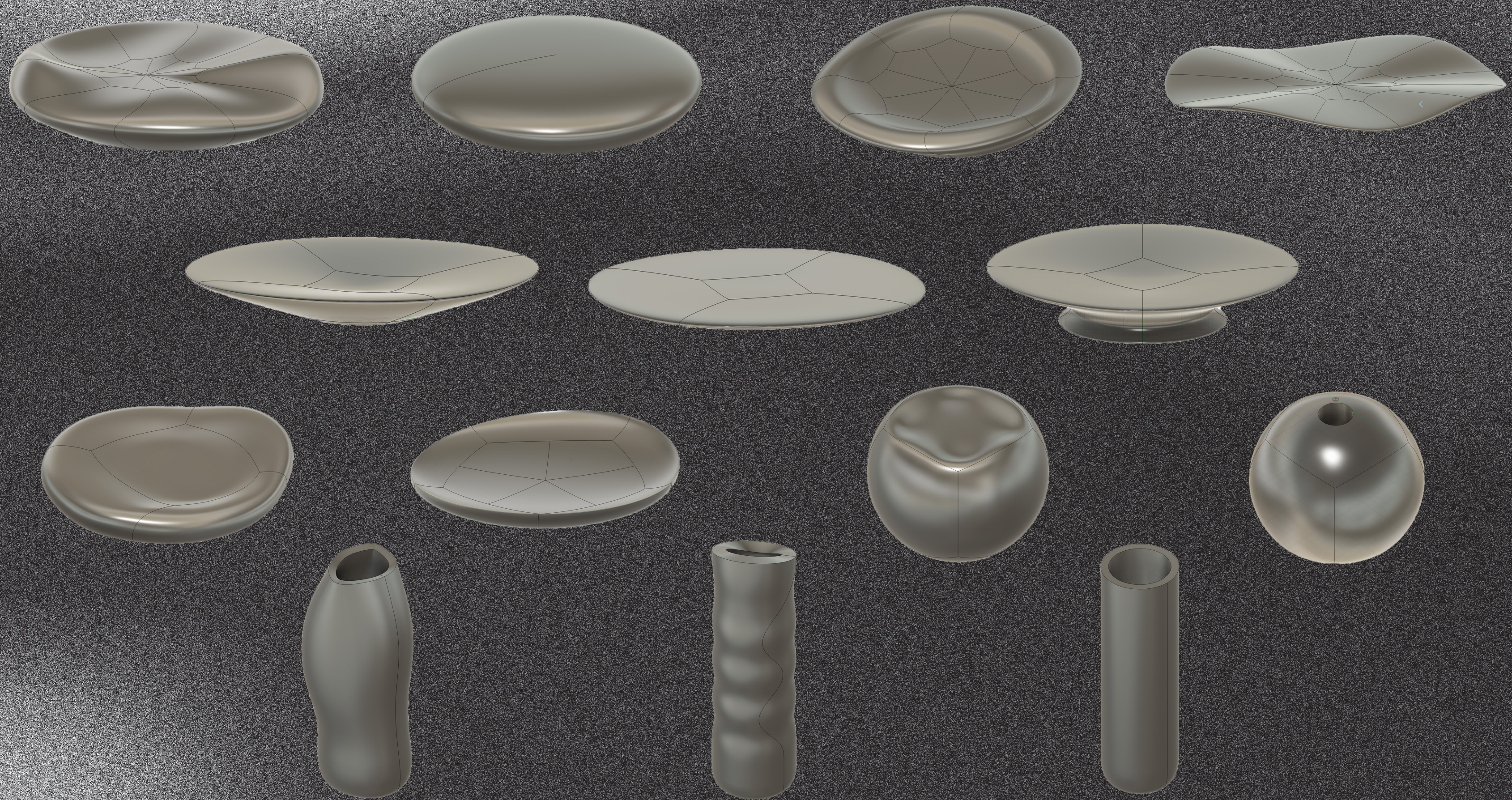
-31.2 g of CO₂
(≈0.031 kg of CO₂ / Approximately)

For comparison, conventional petrochemical production of a 130 mL plastic plate results in a carbon footprint of roughly 0.03–0.07 kg CO₂e (about 30–70 g CO₂e), with approximately 0.05 kg CO₂e being a reasonable estimate for a ~15 g plate.

※Woody, ‘What Is the Carbon Footprint of Plastic?’, n.d. https://woody.com/carbon_neutrality/what-is-the-carbon-footprint-of-plastic/#:~:text=Tom%20continues%20by%20explaining%20that,%E2%80%9D [accessed 16 February 2025].

Reference

Design Ideation



Drawing inspiration from the concept of “CO₂ alescence,” I have developed an organic, airy, and minimalist design aesthetic. This project evolved through iterative stages beginning with conceptual sketches, advancing to 3D printed prototypes, and culminating in the final materialized product.

Design for Perception Change

Our society faces planetary-scale challenges and ambitious goals.

Achieving these objectives depends on the small, everyday behavioral changes made by individuals, the cumulative effect of which can create a significant impact.

Yet, from an individual perspective, how many people have truly adjusted their behavior to tackle today’s challenges?

In reality, it is difficult to prioritize societal agendas over personal concerns, and in doing so, we may inadvertently exacerbate environmental issues.

The fact is, many of us have not yet reached the stage of behavioral change.

We must first further shift their perceptions more.

Before any behavioral change can occur, our perceptions must evolve.

Design is our catalyst.

I intend to harness the power of design to facilitate this transformation.

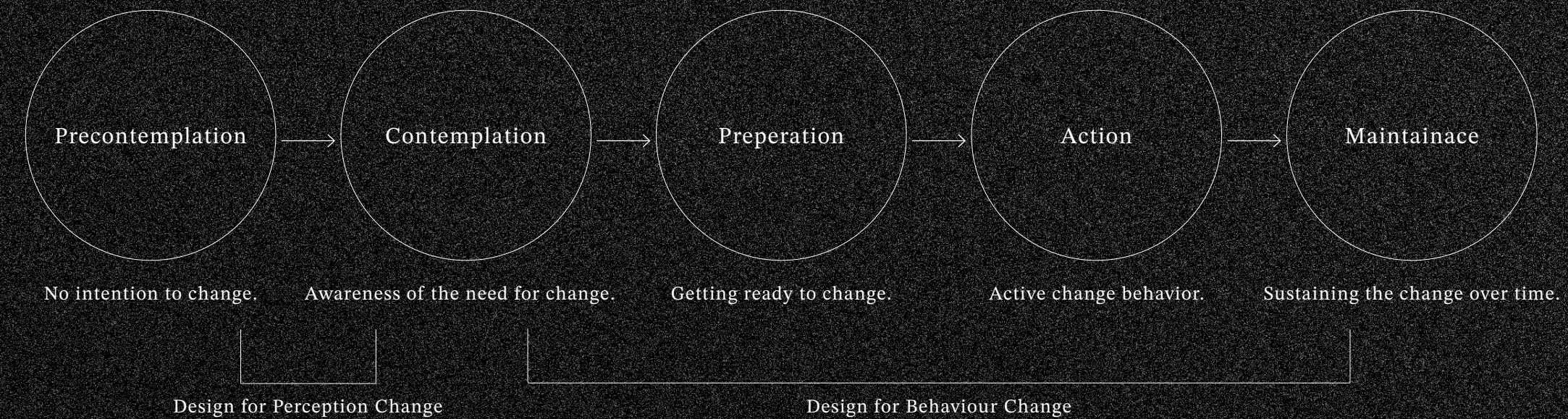
While no single design solution can solve all the challenges we face,

every design has the potential to change perceptions,

and I believe the accumulation of these shifts is the first step

toward meaningful behavioral change.

Transtheoretical Model (Stages of Change)



By referring to the Transtheoretical Model (Stages of Change), design interventions for behavioral change can be divided into two parts.

The first is Design for Perception Change, which aims to move individuals from the “Precontemplation” to the “Contemplation” phase.

The second is Design for Behavior Change, which targets progression through the “Preparation,” “Action,” and “Maintenance” phases.

Ideally, an effective design intervention encompasses both approaches; however, designers may focus on one over the other depending on the specific goals of their project.